Preliminary Assessment of Downscaled Meteorological Inputs to CMAQ Future Climate Simulations

Ad Hoc Meteorological Meeting

6/26/2008

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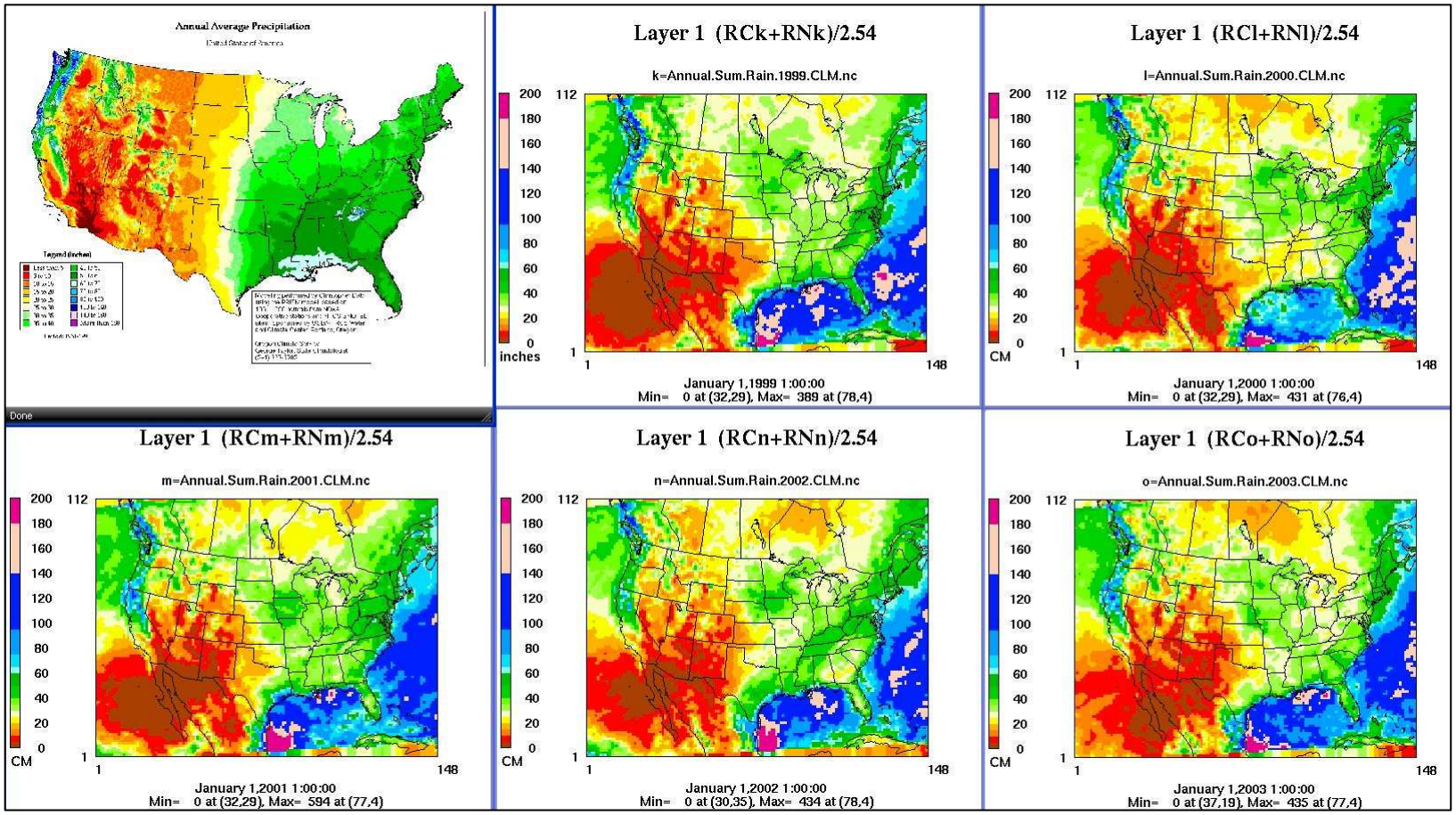
Overarching questions (1)

- Goal is to assess the effects of climate change on AQ.
  - Comparing results of an AQ model driven by “current” and “future” meteorology
  - Meteorological inputs are from dynamically downscaled global climate runs
- How is dynamically downscaled meteorology prepared?
  - Regional-scale meteorological models are driven by lateral boundary and surface conditions from a global model.
  - Numerous user-configuration choices (model physics, how-to’s of BC, etc.)
- What do we know about the “evaluation” of the dynamically downscaled meteorology?
  - Initial evaluations focused on regional climate (MM5) simulations driven by NCEP/NCAR reanalysis data. (e.g., Leung et al. (2003, 2004))
  - More recent evaluations have focused on the “free running” regional climate (MM5) simulations driven by GISS global climate model (e.g., Gustafson and Leung (2007) and Zhang et al (2008))
  - Most papers have concluded that while quantifiable biases existed … they were not enough to invalidate use of the meteorological outputs in the AQ simulations
    - There may be available literature/analyses that have also considered these questions, that AQMG has not yet acquired

Overarching questions (2)

- How does one evaluate the meteorological outputs of a regional climate modeling scenario?
  - Obviously we cannot evaluate the GISS/MM5 (free-running) output fields like we would one of our retrospective MM5 simulations (no time-paired observations).
  - But one can assess whether the “current-year” meteorological fields represent the bulk climatology of the present-day atmosphere.
    - Q1: does the GCM met reproduce annual means of basic met parameters?
    - Q2: does the GCM met reproduce the basic spatial distribution of key met parameters?
    - Q3: does the GCM met exhibit the same interannual variability in meteorology that we see in our retrospective meteorology or, more importantly, in the actual atmosphere?
  - Goal of “evaluation” is not to invalidate the use of GCM-derived meteorological inputs, but to better understand how deficiencies may impact certainty of AQ modeling conclusions regarding the impacts of climate change.
- Early indications are that there are questions about the downscaled meteorology going into EPA’s CMAQ climate applications.
  - Considered those met parameters though to most influence AQ: temperatures, precipitation, PBL heights, winds, and clouds.
  - Issues appear to exist with annual precipitation amounts and patterns; PBL heights and pattern; & summertime maximum temperatures.

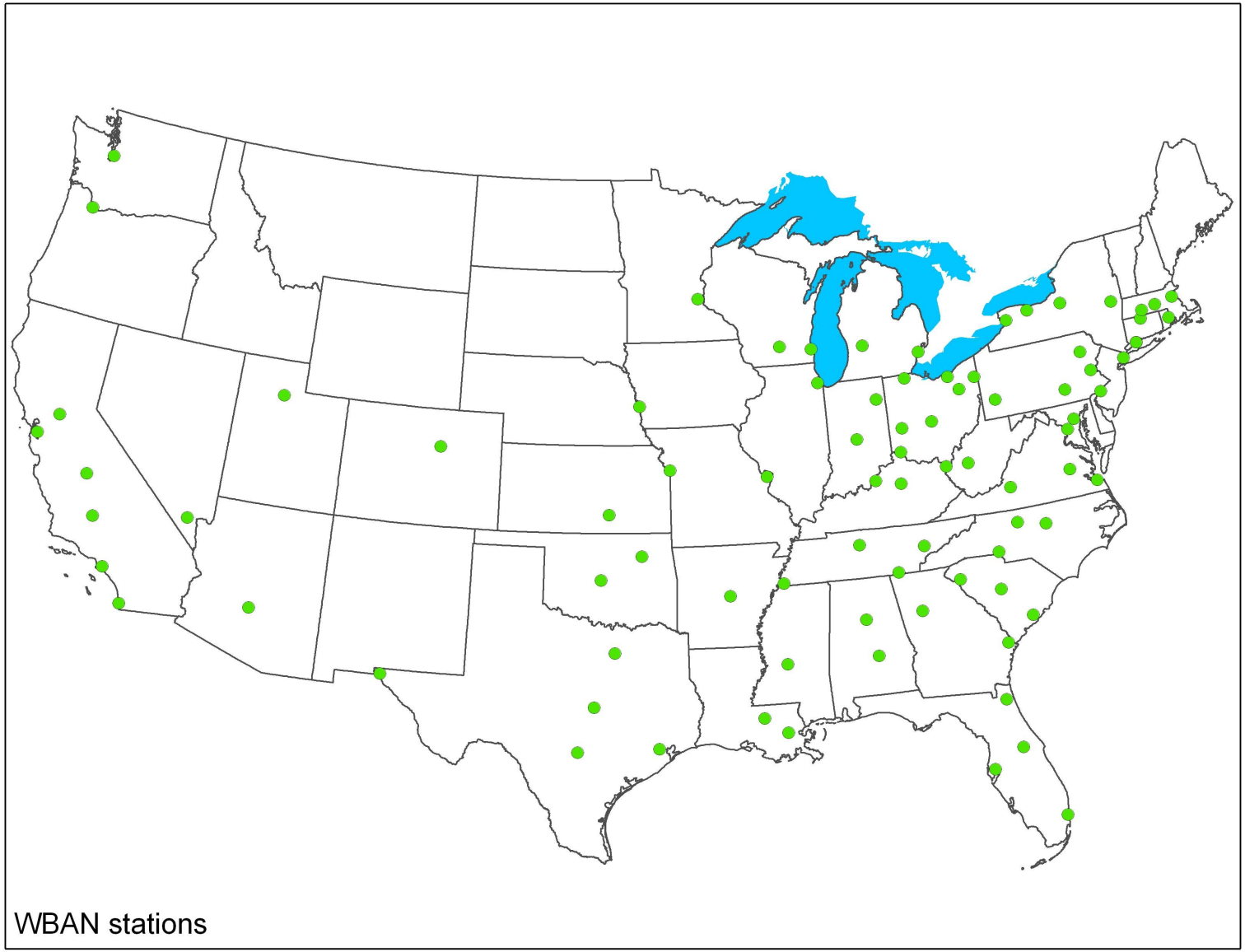
Comparison of individual current-year downscaled annual precipitation against 30-year observation data



- Current 5 years of downscaled meteorology does not appear to reproduce annual precipitation patterns and amounts.
  - appears to be underestimating annual precipitation in the Southeast U.S.
  - appears to be overestimating in the far Northeast U.S. and Great Plains

Map of 85 “representative” sites

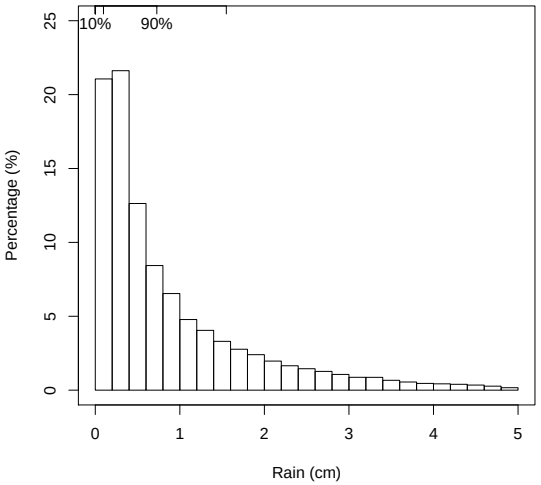
(currently used to compared downscaled met vs. retrospective 2001/02 MM5)
(eventually will be used to compare downscaled vs. ambient data)



Comparison of Daily Precipitation Distributions

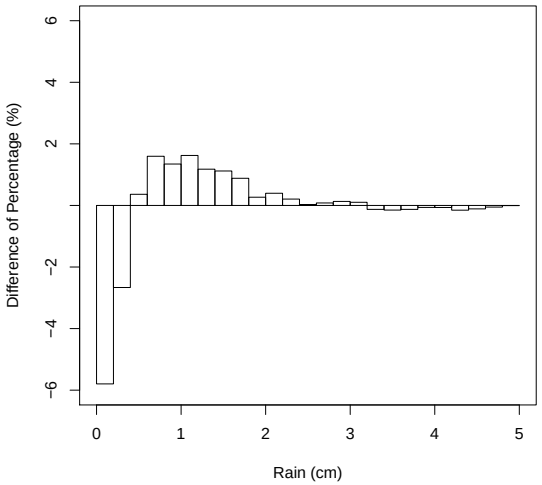
(Downscaled vs. Retrospective Met at 85 representative sites)

Downscaled



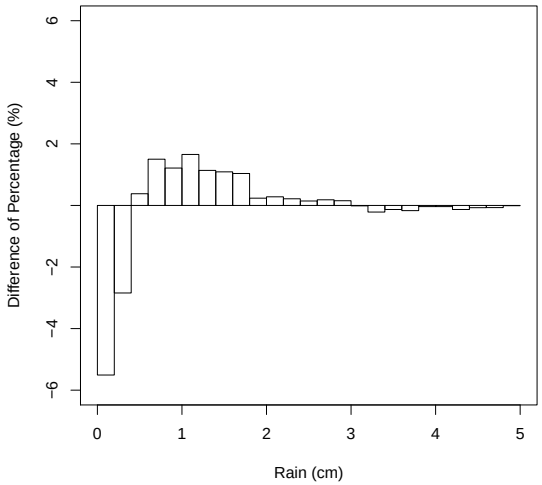
Retrospective – Downscaled

(2 years v. 5 years)

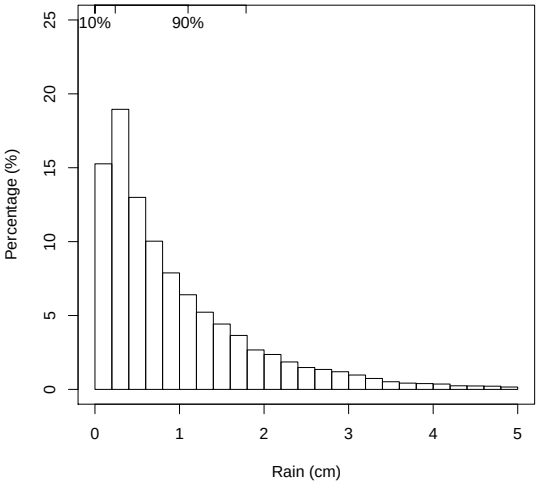


Retrospective – Downscaled

(2 years v. 2 years)



Retrospective

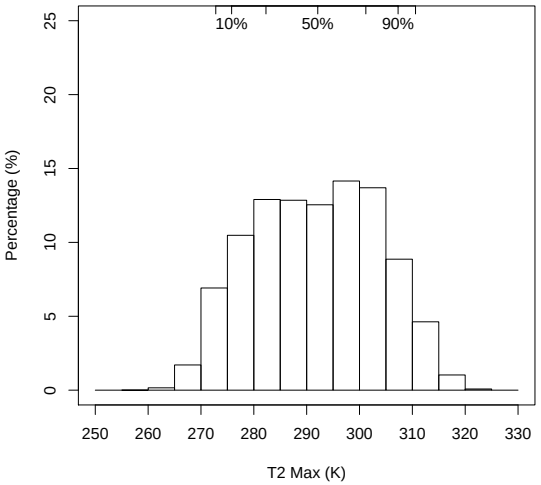


- Downscaled meteorology contains more precipitation-free days (not shown)
- On days w/ precipitation, the downscaled meteorological fields tend to generate more days w/ light precipitation totals (e.g., < 0.15 in)
  - Climate modeling has slightly more of the rare, high precipitation days (e.g., > 1.0 in)
- *Future climate modeling tends to show that rainy days will yield more precipitation in the future*

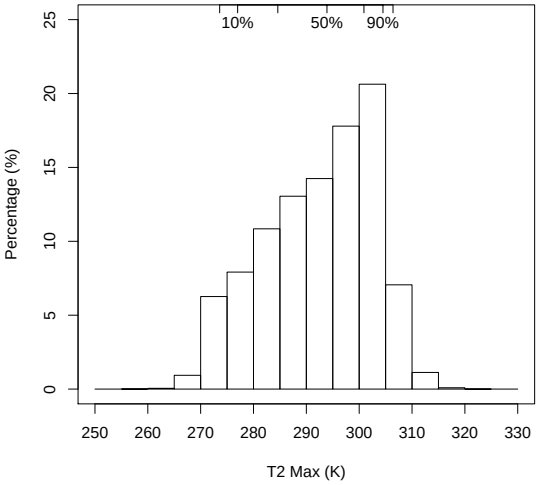
Comparison of Daily Max Temperature Distributions

(Downscaled vs. Retrospective Met at 85 representative sites)

Downscaled

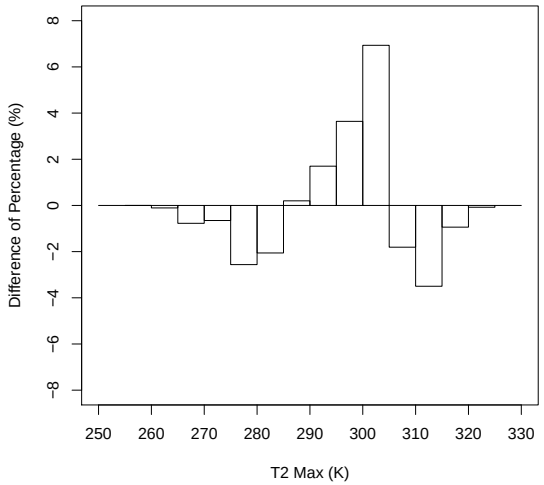


Retrospective



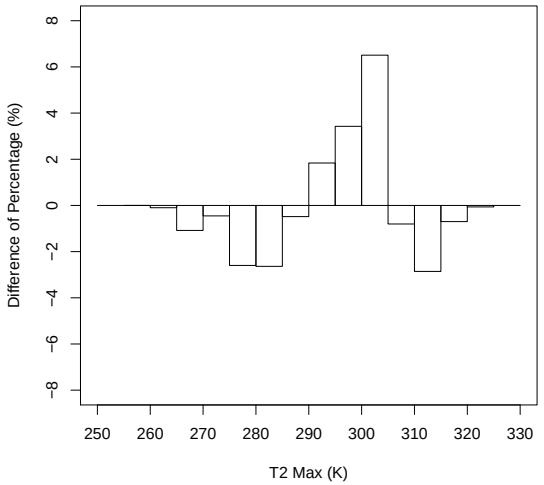
Retrospective – Downscaled

(2 years v. 5 years)



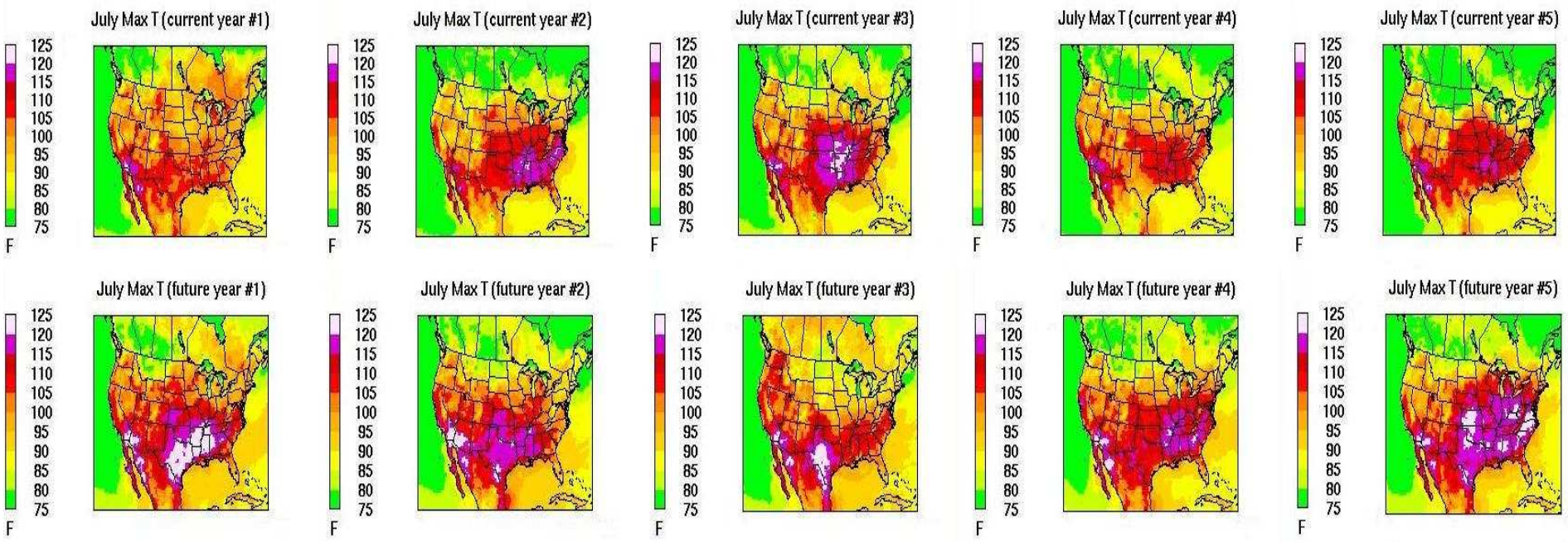
Retrospective – Downscaled

(2 years v. 2 years)



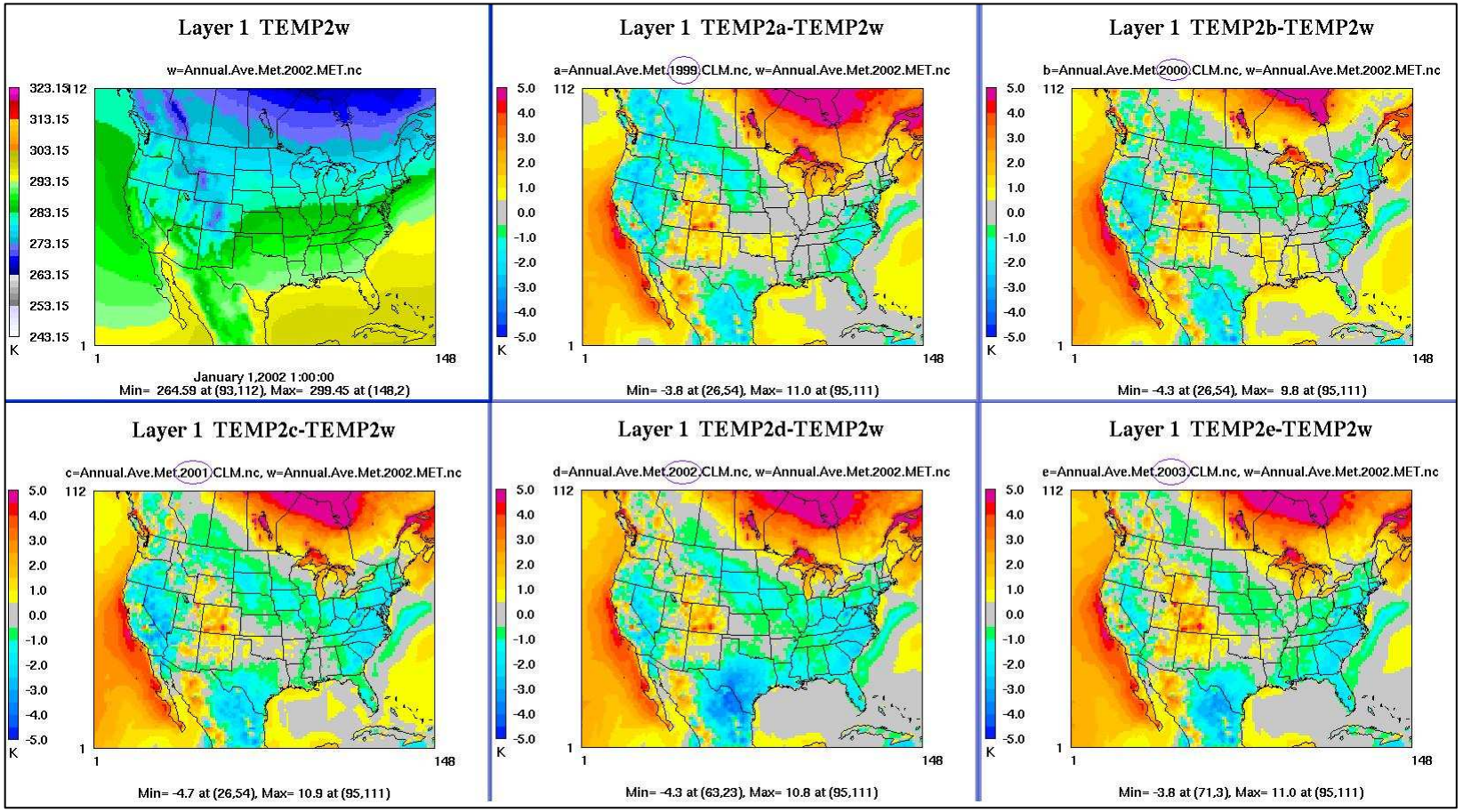
- Downscaled meteorology generates more “extreme” conditions
  - more cool highs (< 285K) and more warm highs (>305K)
- Downscaled meteorology generates 5x more days with max temperatures > 310K (~ 100F)
- *Future climate modeling tends to show that max temperatures will increase in the future*
  - *90^{th} percentile > 310K*

Monthly Max (July) Temperatures in Downscaled Climate Meteorological Data



- Max summer temperatures in the southern parts of the U.S. appear too warm in the downscaled meteorology
- Max summer temperatures appear too cool in some northern parts of the domain
- AQ concentrations can exhibit nonlinear relationships w/ meteorological parameters

Comparison of individual current-year downscaled annual average temperatures against 2002 MM5

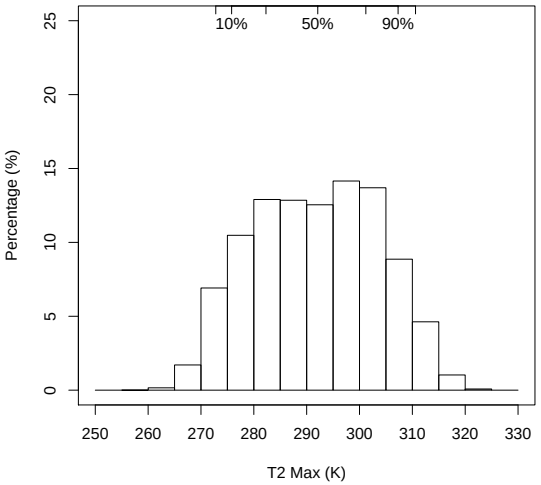


- Appear to be persistent (methodological) differences in annual mean temperatures
  - Climate runs tend to be warmer over water, Hudson Bay, & high terrain areas
  - Climate runs tend to be slightly cooler elsewhere.

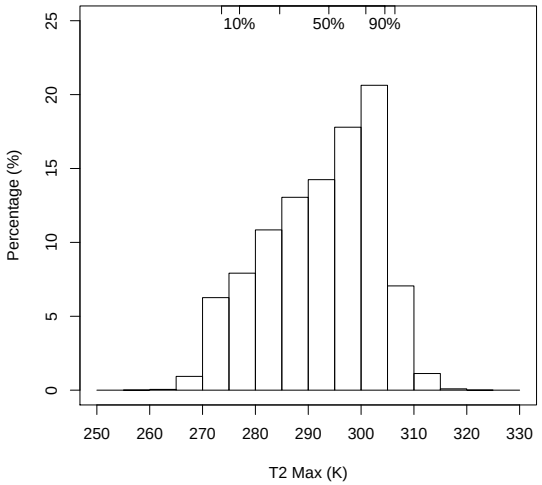
Comparison of Daily Max Temperature Distributions

(Downscaled vs. Retrospective Met at 85 representative sites)

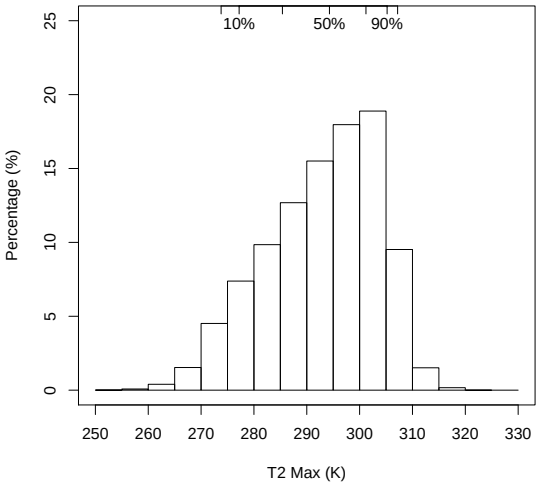
Downscaled



Retrospective



Obs (1995-2007)

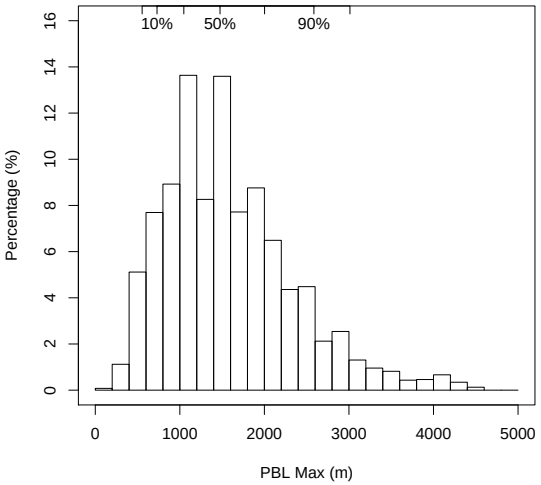


- Downscaled distributions of daily maximum temperatures appear to vary from the 13-year observational histogram.
  - especially in the > 310K range
- Retrospective 2001-2002 MM5 seem to match observational distributions more closely

Comparison of Daily Max PBL Distributions

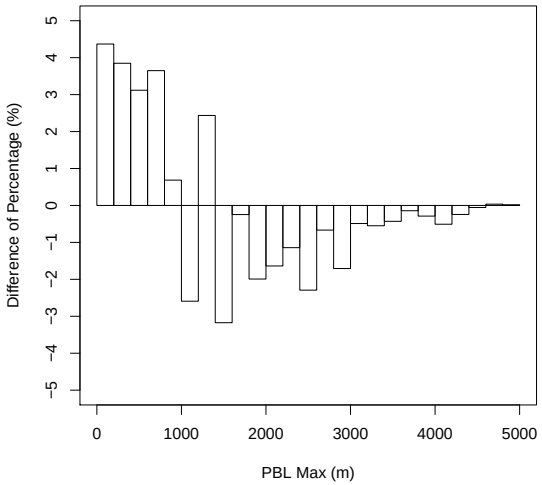
(Downscaled vs. Retrospective Met at 85 representative sites)

Downscaled



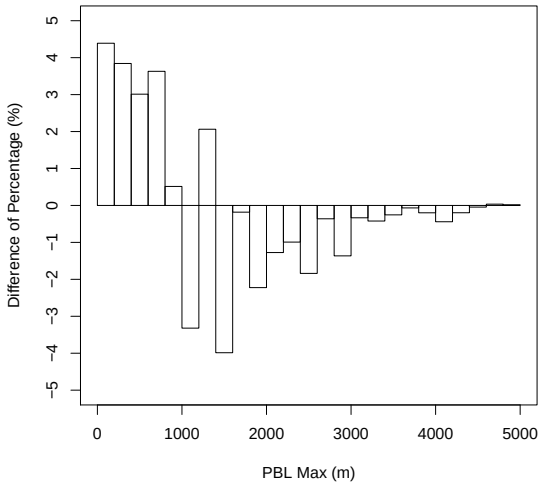
Retrospective – Downscaled

(2 years v. 5 years)

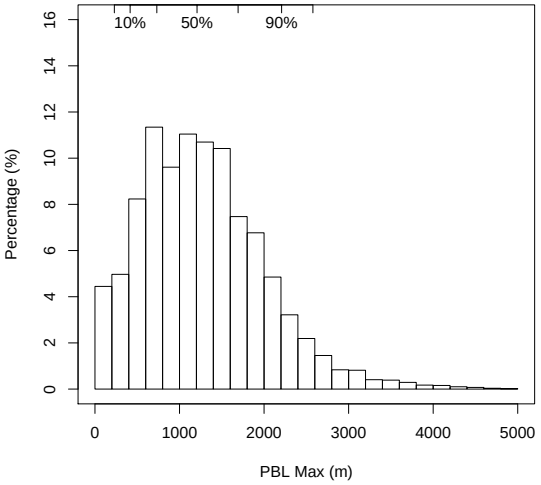


Retrospective – Downscaled

(2 years v. 2 years)

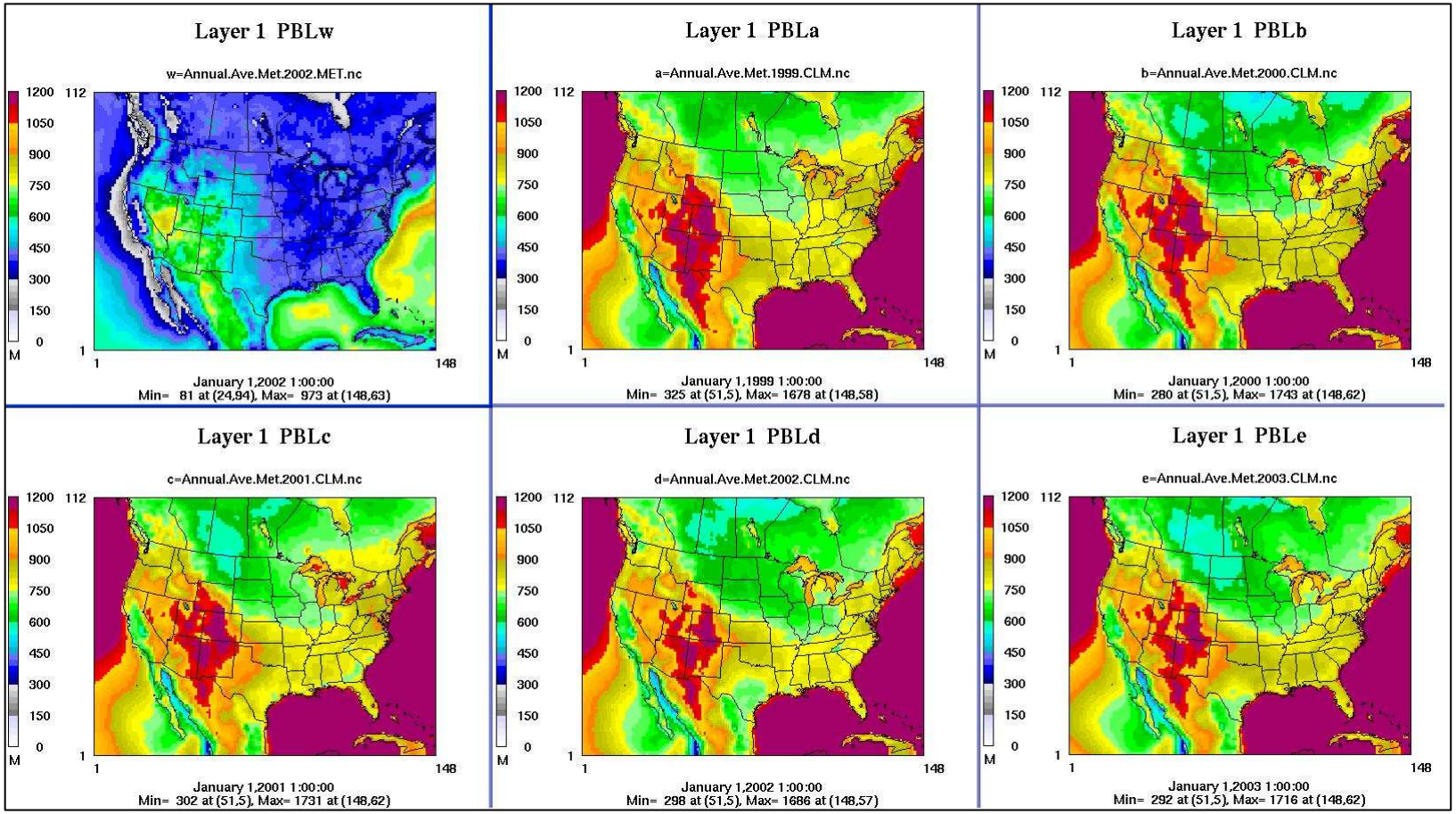


Retrospective



- Downscaled meteorology simulates many more site/days with max PBL > 1600 m
- Downscaled meteorology generates almost no days where max PBL < 200 m
- *Future climate modeling tends to show that max PBLs will increase in the future*
  - *Current vs. Future differences are smaller than retrospective vs. downscaled differences.*

Comparison of individual current-year downscaled annual average PBLs against 2002 retrospective MM5

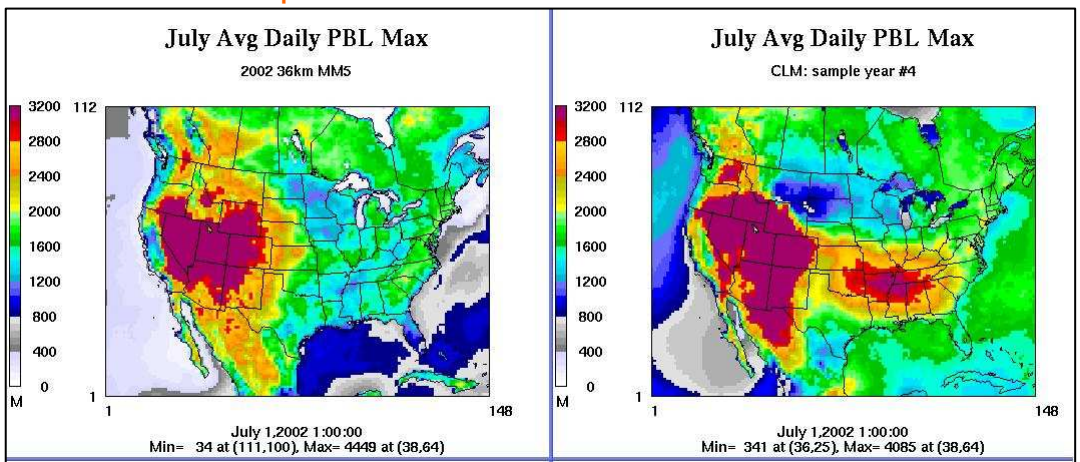


- Downscaled meteorology will allow significantly more mixing at all locations
- Differences in spatial patterns (downscaled vs. retrospective)

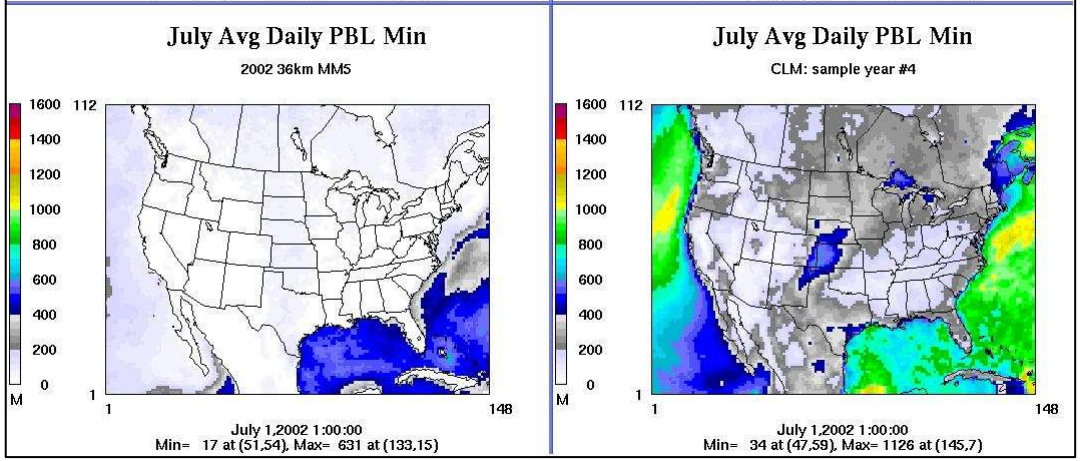
Comparison of sample current-year downscaled July average PBL against 2002 retrospective MM5

Retrospective | Downscaled

Daily Max



Daily Min

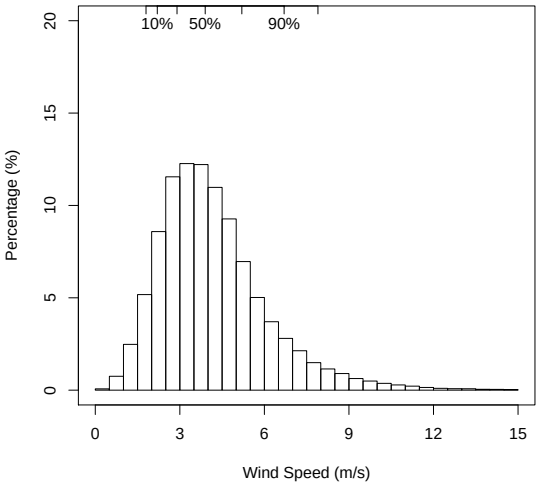


- Again, there are large differences in spatial patterns.
- Downscaled PBLs are higher both day (max PBL) and night (min PBL).

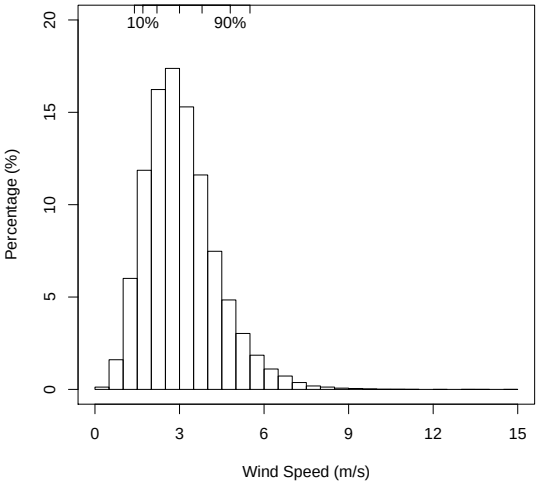
Comparison of Daily Avg Wind Speed Distributions

(Downscaled vs. Retrospective Met at 85 representative sites)

Downscaled

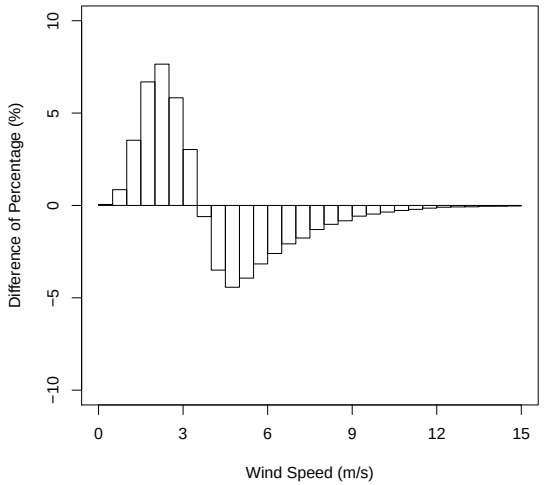


Retrospective



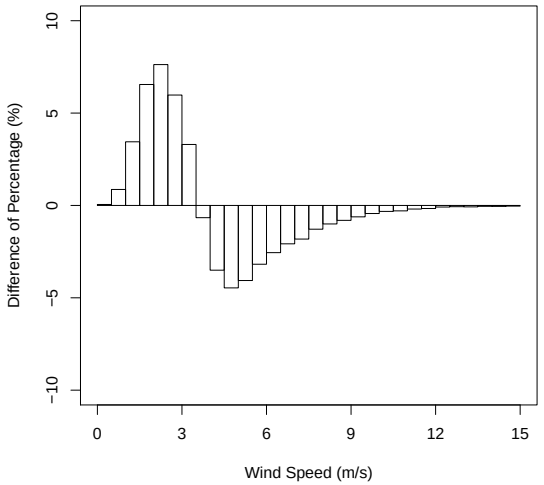
Retrospective – Downscaled

(2 years v. 5 years)



Retrospective – Downscaled

(2 years v. 2 years)

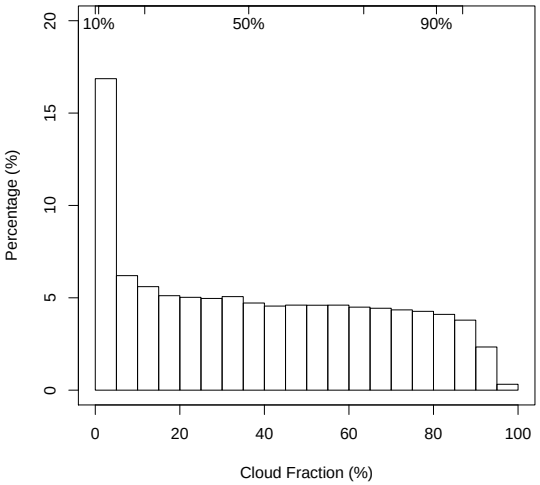


- There are large differences in the distributions of wind speed between the two meteorological data sets
- The downscaled meteorology tends to generate more days with higher daily average wind speeds.
- *Future climate modeling tends to show that daily average wind speeds do not change greatly from current conditions.*

Comparison of Daily Avg Cloud Fraction Distributions

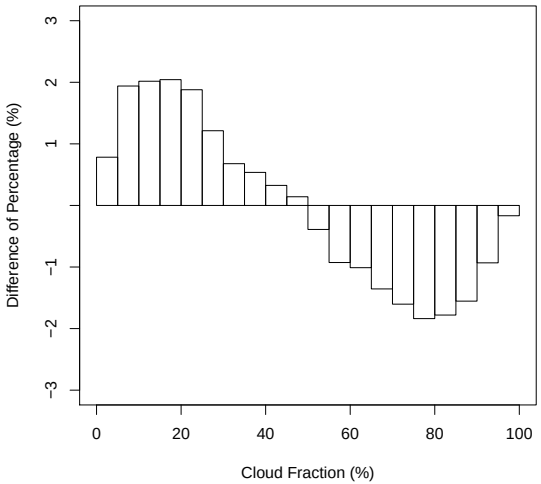
(Downscaled vs. Retrospective Met at 85 representative sites)

Downscaled



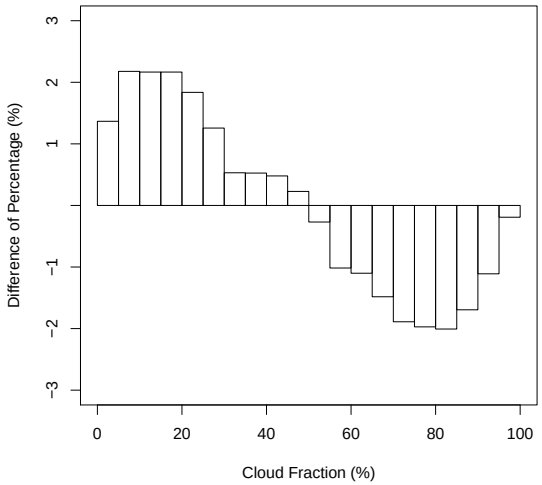
Retrospective – Downscaled

(2 years v. 5 years)

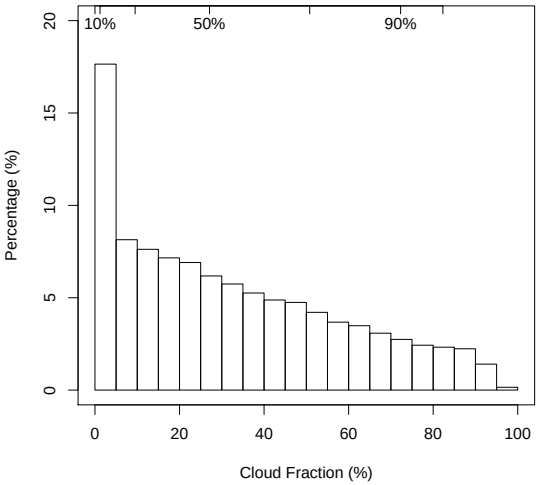


Retrospective – Downscaled

(2 years v. 2 years)

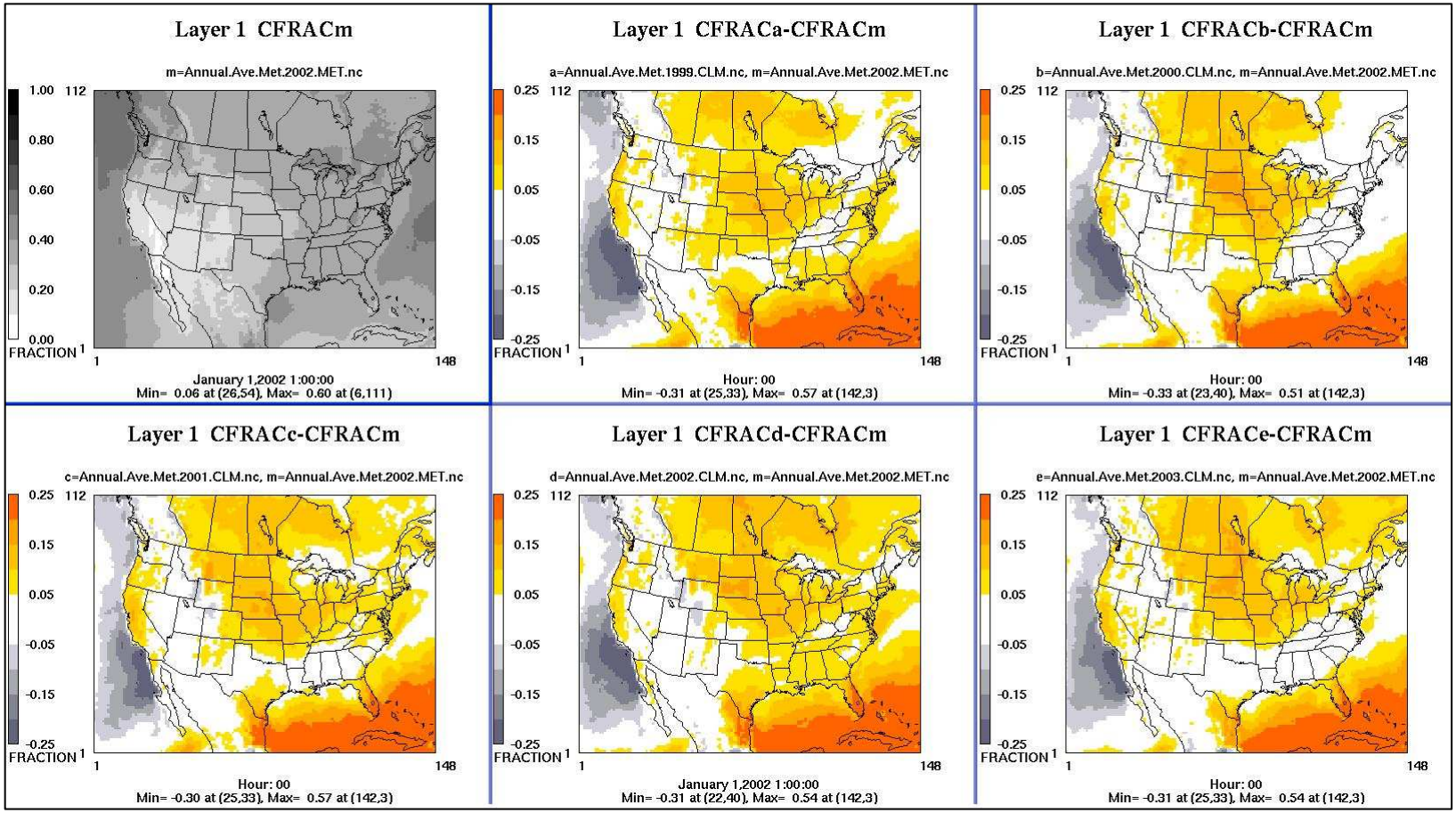


Retrospective



- Downscaled meteorology simulates more “cloudy” days (average CFRAC > 50%).
- Cloud fractions are more similar in the downscaled and retrospective meteorological fields than other met parameters.
- *Future climate modeling tends to show that average cloud fractions do not change greatly from current conditions. (slight tendency for more clear & overcast)*

Comparison of individual current-year downscaled annual cloud fractions against 2002 retrospective MM5



- Appear to be persistent (methodological) differences in annual cloud fractions
  - Climate runs tend to be sunnier over water (esp., off CA)
  - Retrospective runs tend to have more sun over most of the U.S. and Gulf of Mexico

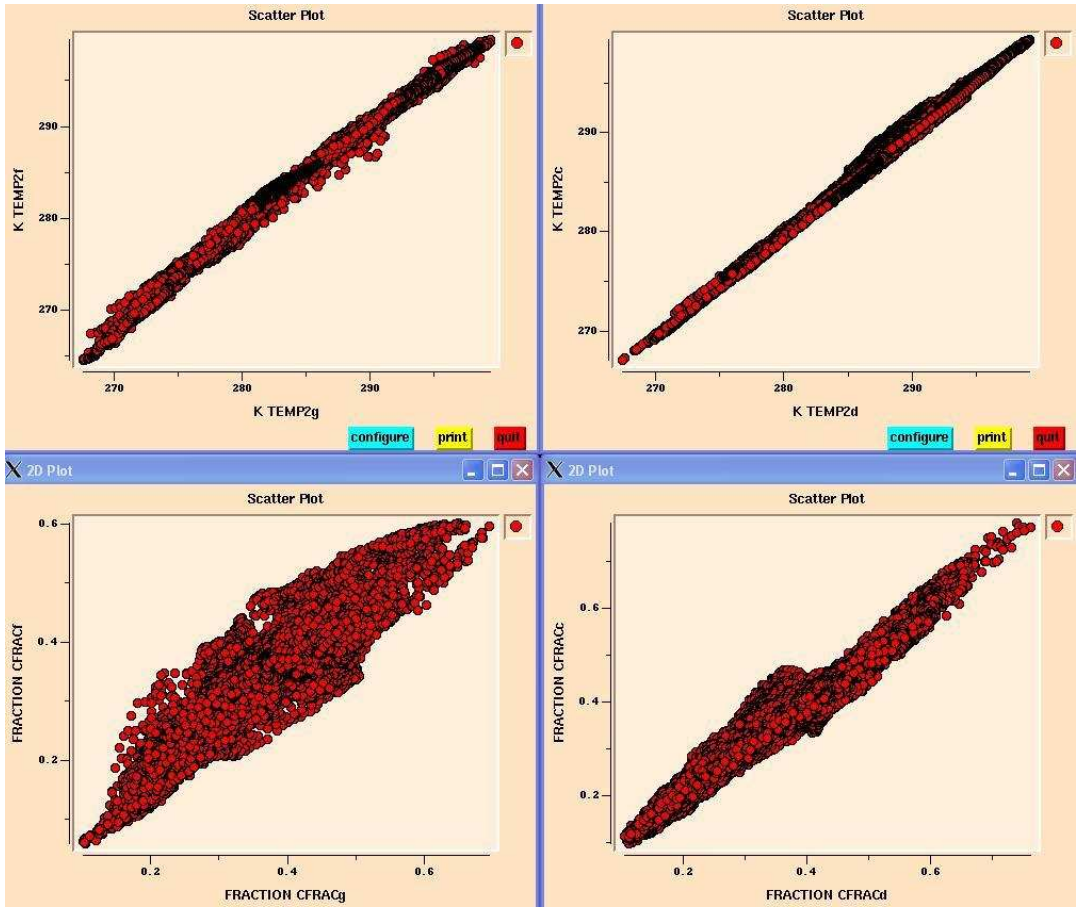
How does interannual variability compare?

(sample downscale years vs. 01/02 retrospective)

Retrospective | Downscaled

Annual Average Temperature

Annual Average Cloud fraction



- Appears to be greater differences in 2001/02 MM5 than what is seen in downscaled meteorology.
- *Climate modeling indicates that interannual variability will increase in the future (not shown)*

Very Initial Conclusions

- There appear to be instances in which the GISS/MM5 downscaled meteorological output fields do not reproduce the climatological annual means of certain key parameters (e.g. precipitation, temperatures).

- There appear to be differences in the basic spatial distributions of key meteorological parameters between the downscaled meteorological fields and existing retrospective meteorological data (e.g., precipitation, temperatures.

- At first glance, it appears that the interannual variability of the (1999-2003) downscaled climate meteorological data may underestimate what occurs in the current atmosphere (using the retrospective model output as a proxy).

- These results may have implications for the use of the downscaled climate meteorological data:
  - If the model is unable to reproduce existing conditions or interannual variability, can it predict future changes in those conditions?
  - How will some of the apparent anomalies in the downscaled meteorological fields influence AQ modeling simulations that use these fields as inputs?

Other thoughts / Next steps @ OAQPS

- There are two basic ways to predict the effects of climate change on AQ (Gustafson and Leung, 2007):
  - Account for climate-driven changes in meteorological fields in the inputs to AQ models via dynamic downscaling. *(CI-CPAQ, CIRAQ, and others)*
  - Determine statistical relationships between meteorology and AQ & then infer how climate-driven changes in met parameters will impact AQ.

- On-going work on statistical AQ/met interaction
  - Generalized linear models exist between ambient AQ/met (Camalier et al 2007)
  - Are in the process of analyzing AQ/met interactions in 2002 CMAQ simulation
    - will indicate whether AQ models like CMAQ exhibit the same relationships between meteorology and AQ as seen in the real atmosphere, if not … many ramifications on use of CMAQ modeling to account for climate-driven met changes
  - Next step would be to assess whether existing AQ/met relationships change between the current climate years and the future climate years
  - Last step: make conclusions about expected future climate changes on AQ based on predictions from entire suite of existing GCMs and scenarios.

Other thoughts / Next steps @ OAQPS

- Intend to collaborate with climate partners on next round of downscaled meteorological inputs to AQ models
  - Need for assessment of current climate conditions from GCMs (e.g., SST)
  - May need to conduct sensitivity testing to see how AQ modeling results would change as a result of varying:
    - GCM outputs
    - MM5 physics configurations
    - Choices in incorporating climate effects at lateral/surface boundaries
    - Horizontal/vertical resolution